

ON THE EXISTENCE OF C-13 DEPLETED CARBON IN THE MANTLE,
EVIDENCE FROM DIAMOND STUDIES

P. Deines

Department of Geosciences
The Pennsylvania State University
University Park, PA 16802

J. W. Harris

Department of Applied Geology
University of Strathclyde
Glasgow G1 1X3

J. J. Gurney

Geochemistry Department
University of Cape Town
Rondebosch 7700
South Africa

The concept that primitive mantle carbon can be characterized by a single carbon isotope ratio around which relatively small variations occur can no longer be accepted without question.

Carbon isotope studies of intrusive and extrusive carbonatites and carbonate tuffs indicate that there is a north - south trending zone of carbonatites in East Africa, between the Eastern and Western Rift, which is characterized by average carbon isotopic compositions between -2.4 and -4.4 o/oo vs. PDB. Eastern and Western Rift carbonatites on the other hand show carbon isotopic compositions between -5 and -8 o/oo vs. PDB. Investigations of the carbon isotopic composition of well characterized diamonds have shown that there are small but significant differences in the mean ^{13}C -content of diamonds suites from different diatremes. For example: Premier -4.87 ± 1.87 o/oo vs. PDB ($n = 176$), Finsch -5.99 ± 1.11 o/oo vs. PDB ($n = 93$), Dan Carl -3.34 ± 0.95 o/oo vs. PDB ($n = 91$), Koffiefontein -5.52 ± 2.07 o/oo vs. PDB ($n = 56$), New Elands -5.53 ± 0.69 o/oo vs. PDB ($n = 18$). In the sample suites from these kimberlites highly ^{13}C depleted diamonds are absent or rare. A larger number of such specimens has been found, however, among samples from the Roberts Victor and the Orapa kimberlite.

In the sample suite from the Roberts Victor kimberlite diamonds with peridotitic inclusions show a narrow range -5.43 ± 0.94 o/oo vs. PDB ($n = 65$). Diamonds containing eclogitic inclusions can be subdivided on the basis of their carbon isotopic composition into two groups: Group-A, -15.52 ± 0.40 o/oo vs. PDB ($n = 10$); Group-B, -5.89 ± 0.39 o/oo vs. PDB ($n = 3$). Within each group the isotopic composition variation is rather small. Comparison of the chemical composition of clinopyroxenes from diamonds of Group-A and Group-B reveals significant differences. Clinopyroxenes from diamonds of Group-A are enriched in Al, Fe, and Mn and depleted in Si, Mg, and Ca compared to clinopyroxenes from Group-B diamonds. The latter are in composition similar to those of the clinopyroxenes from graphite-diamond eclogites. Corresponding compositional grouping are observed for the garnet inclusions. The difference in composition between the inclusions from the two groups is very much larger than the variations generally produced during igneous fractionation processes. Hence it is not likely that the two groups are related through a single such process.

Among the close to 200 garnets from eclogite xenoliths that have been analyzed by Hatton (1978) there is only one that has Fe and Mn enrichments that are similar to those observed in the inclusions in diamonds. This particular garnet occurs within a larger clinopyroxene. Since the enclosing clinopyroxene does not show a similar extreme enrichment in these two elements disequilibrium between host and inclusion is suggested. One might hence interpret the garnet inclusion in the clinopyroxene as a

relict of an earlier crystallization event in which the inclusions found in the Group-A diamonds were also formed.

As from the Roberts Victor kimberlite eclogites have been described that show unusual oxygen isotopic compositions it is of interest to investigate whether there is any reason to suggest that the unusual carbon and oxygen isotopic compositions might be related. The compositions of the garnets and clinopyroxenes from diamond inclusions have been compared in terms of ACF components with the bulk compositions of the eclogite xenoliths whose oxygen isotopic composition have been measured. It is found that the bulk compositions deduced from the inclusions in diamonds of a carbon isotopic composition of -15 o/oo vs. PDB are akin to compositions of eclogites that have oxygen isotopic compositions around 6 o/oo vs. SMOW (normal mantle). Bulk compositions deduced from graphite-diamond eclogites with carbon isotopic compositions of about -5 o/oo vs. PDB are similar to those of eclogites with oxygen isotopic compositions of about 3 o/oo vs SMOW (^{18}O depleted compared to normal mantle). More recently acquired data (McGregor private communications) indicate that clinopyroxenes depleted in ^{18}O with respect to normal mantle compositions have FeO and MnO contents that are generally lower than those of clinopyroxenes from eclogites of normal oxygen isotopic compositions and very much lower than those of the clinopyroxenes from ^{13}C -depleted diamonds. Hence the available data do not point to an association between the depletion in the heavy isotopes of carbon and oxygen in the eclogitic material from the Roberts Victor kimberlite.

The carbon isotopic composition of diamonds from the Orapa kimberlite shows a range from -2.5 to 22.5 o/oo vs. PDB ($n = 148$). Within this range one may distinguish 4 modes. Mode-1 (M1) occurs between -4 to -8.5 o/oo (75 samples), Mode-2 (M2) between -9 and -12.5 o/oo (10 samples), Mode-3 (M3) between -13 to -16.5 o/oo (21 samples), and Mode-4 (M4) between -16.5 to -20.5 o/oo (35 samples). There are insufficient data to establish whether there are additional modes at -2.5 to -3.5 o/oo (3 samples) or -21 to -22.5 o/oo (4 samples). The chemical composition of the inclusions may differ depending on the carbon isotopic composition of the host. For example 4 olivine samples coming from hosts belonging to M1 have a mean forsterite content of $92.72 \pm 0.45\%$ while an olivine from a host belonging to M4 has the lowest forsterite content (92.2) of the samples suite. Five orthopyroxenes ($\text{SiO}_2 = 55.03 \pm 0.66$, $\text{Al}_2\text{O}_3 = 0.56 \pm 0.18$, $\text{FeO} = 11.91 \pm 2.50$, $\text{MgO} = 30.19 \pm 1.70$) from hosts belonging to M4 have notably lower silica, alumina and magnesia and higher iron content than the pyroxene ($\text{SiO}_2 = 56.9$, $\text{Al}_2\text{O}_3 = 0.82$, $\text{FeO} = 4.62$, $\text{MgO} = 35.9$) from a host belonging to M1. In both cases the minerals from the ^{13}C depleted hosts show higher iron contents. No hosts belonging to M4 containing chromites were found, however 6 chromites from hosts belonging to M1 show lower alumina and higher titanium contents than a chromite from a diamond belonging to M2.

The most common inclusion mineral in the samples suite from Orapa is garnet. Within some of the carbon isotopic composition modes different garnet composition groups may be recognized; some of them may occur in several of the ^{13}C modes. One can distinguish a group of garnets whose compositions is very similar to that of the garnets in graphite and diamond eclogites (E); it occurs in modes M1, M2, M3, and M4. We may also distinguish a second group (P), occurring, only in M1 characterized by lower iron and higher chrome contents and compositionally akin to the peridotitic garnets frequently encountered among the Premier and Finsch kimberlite diamond inclusions and associated there with iron depleted olivines. In modes M3 and M4 a third compositional group of garnets can be distinguished, which has a lightly lower chrome and much higher iron content than the normal P-Type garnets. Several of the garnets belonging to this compositional group coexists with orthopyroxenes, one with clinopyroxene. The mean composition of five garnets ($\text{SiO}_2 = 40.25 \pm 0.54$, $\text{TiO}_2 = 0.73 \pm 0.26$, $\text{Al}_2\text{O}_3 = 19.63 \pm 1.39$, $\text{Cr}_2\text{O}_3 = 2.93 \pm 1.64$, $\text{FeO} = 14.29 \pm 2.80$, $\text{MnO} = 0.54 \pm 0.11$, $\text{MgO} = 16.82 \pm 1.83$, $\text{CaO} = 4.16 \pm 1.14$) from hosts belonging to M4 is very similar to the mean composition of garnets from three peridotite xenoliths from the Matsoku pipe which show the highest iron contents ($\text{SiO}_2 = 40.83 \pm 0.45$, $\text{TiO}_2 = 0.33 \pm 0.02$, $\text{Al}_2\text{O}_3 = 20.67 \pm 1.13$, $\text{Cr}_2\text{O}_3 = 2.94 \pm 1.63$, $\text{FeO} = 13.06 \pm 0.11$, $\text{MnO} = 0.38 \pm 0.2$, $\text{MgO} = 17.17 \pm 0.26$, $\text{CaO} = 4.38$; Cox et al., 1973). A corresponding similarity is found for the pyroxenes. A comparison of the whole rock compositions of these rocks with the various estimates that have been made for the composition of

primitive mantle indicates that they fall within the range of postulated mantle compositions.

We conclude that the association of ^{13}C depleted diamonds with garnets of compositions that are generally considered as representing most fertile mantle is evidence that ^{13}C depleted carbon is a primary constituent of the mantle underlying the Orapa Kimberlite. Very special circumstances would have to prevail in order that a subduction process would result in the very close correspondence in chemical composition between the garnets from highly ^{13}C depleted diamonds and those from the most fertile ultramafic xenoliths, in particular the combination of high Fe/Mg ratio with moderate chrome contents.

On the basis of the data for the Roberts Victor and Orapa diamonds we suggest that in the mantle regions exists which can show considerable ^{13}C depletion and which can be identified at two localities that are separated by about 1000 km. At a particular locality there can be characteristic chemical signatures associated with the ^{13}C depletion. The common chemical feature that has been observed at the Orapa and Roberts Victor kimberlite is a relative increase in the iron content of the minerals included in the ^{13}C depleted diamonds. Attempts to find a direct link between ^{13}C depletion and a subduction process have not been successful. In view of the general similarity of the carbon isotope distribution in diamonds and meteorites and the association of some of the highly ^{13}C depleted carbon with chemical compositions that are thought to be characteristic for undifferentiated mantle we propose that part of the isotope variability and ^{13}C depletion of diamonds is derived from inhomogeneities remaining from the original accretion of the Earth.

REFERENCES

- Cox, K.G., Gurney J.J. and Harte B. (1973) Xenoliths from the Matsoku Pipe; in: Lesotho Kimberlites. ed. P.H. Nixon, P. 76 - 100.
- Hatton C.J. (1978) The Geochemistry and Origin of Xenoliths from the Roberts Victor Mine. Unpublished Ph.D. Thesis Department of Geochemistry of the University Cape Town, 179 pp.